A Hyperspectral Imager to Meet CLARREO Goals of High Absolute Accuracy and On-Orbit SI Traceability

Greg Kopp, Peter Pilewskie, Ginger Drake, Joey Espejo,
David Harber, and Karl Heuerman

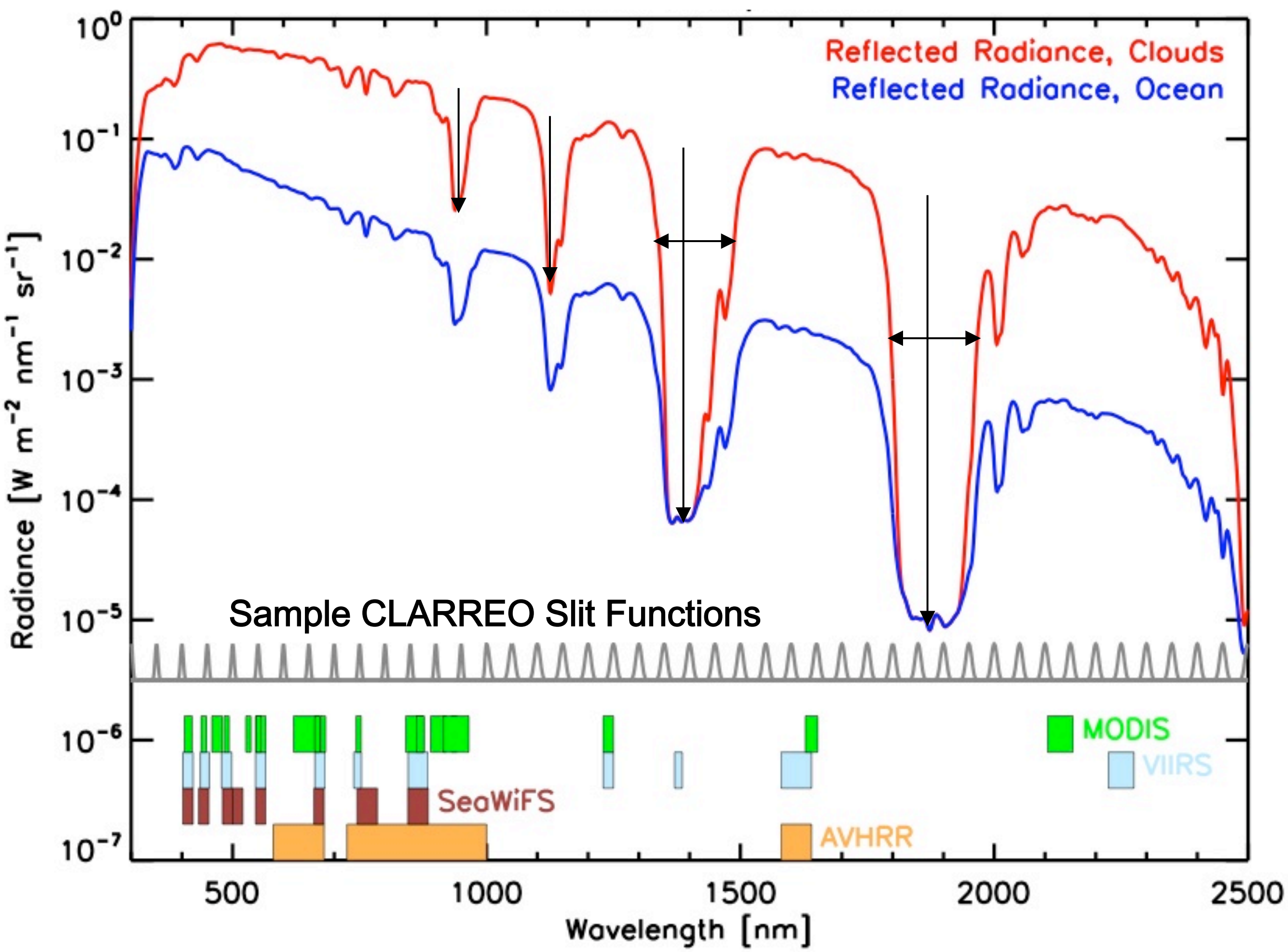
Laboratory for Atmospheric and Space Physics

and

Joe Rice and Howard Yoon

NIST

Consider Detection of Water Vapor Trend



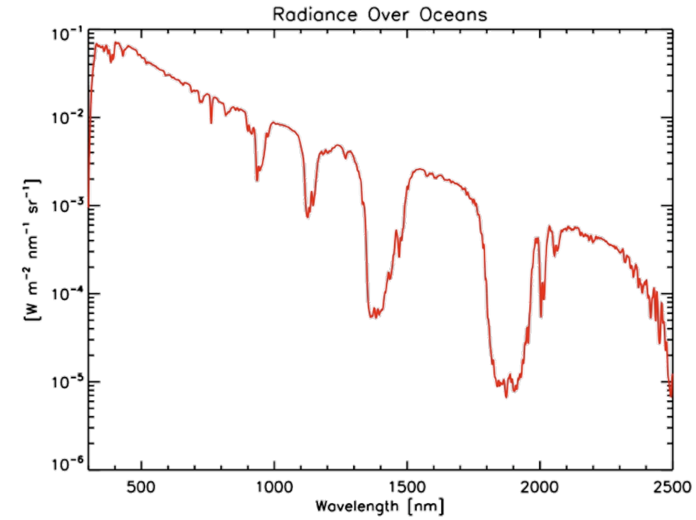
MODTRAN simulations used to predict changes in outgoing spectral radiance due to 0.4 kg/m^2 per decade trend.

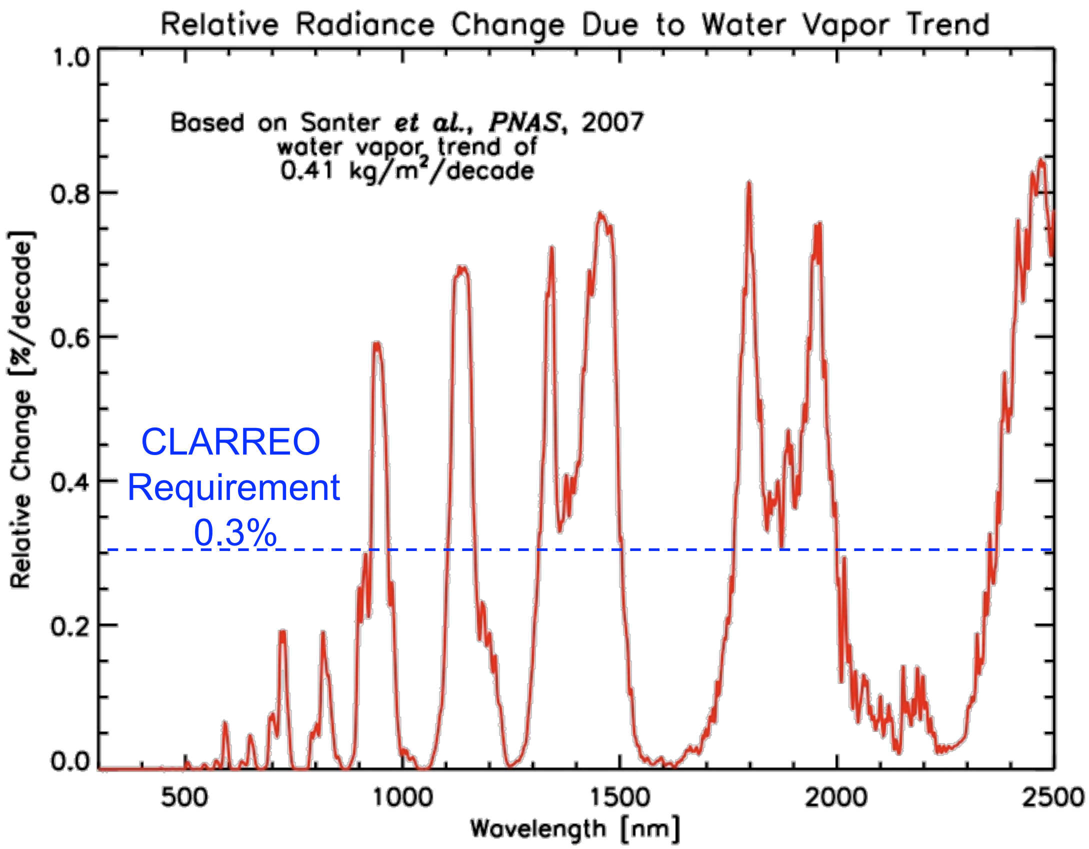
Define accuracy/stability requirements needed to detect trend.

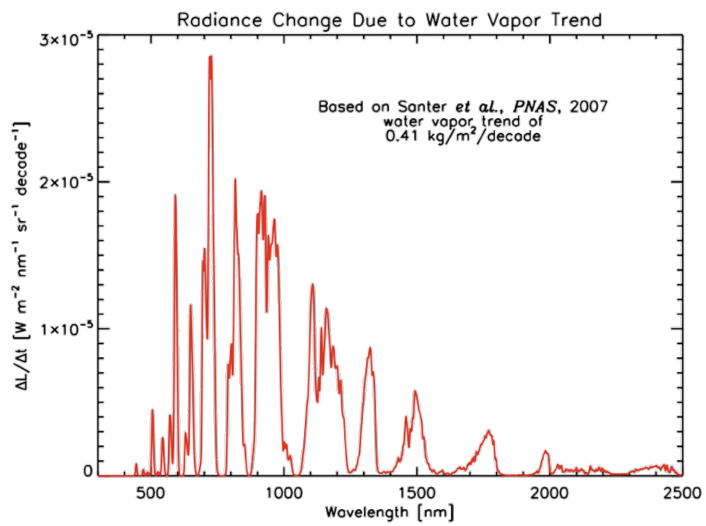
- Requires broad spectral coverage with moderate resolution.
- Averages for climate require broad spatial sampling.

Sensitivity of Earth-Reflected Solar Radiance to Water Vapor

Largest absolute changes (below right) occur in the sub-saturated VNIR water bands; largest fractional changes (below left) in the wings of the stronger SWIR bands.





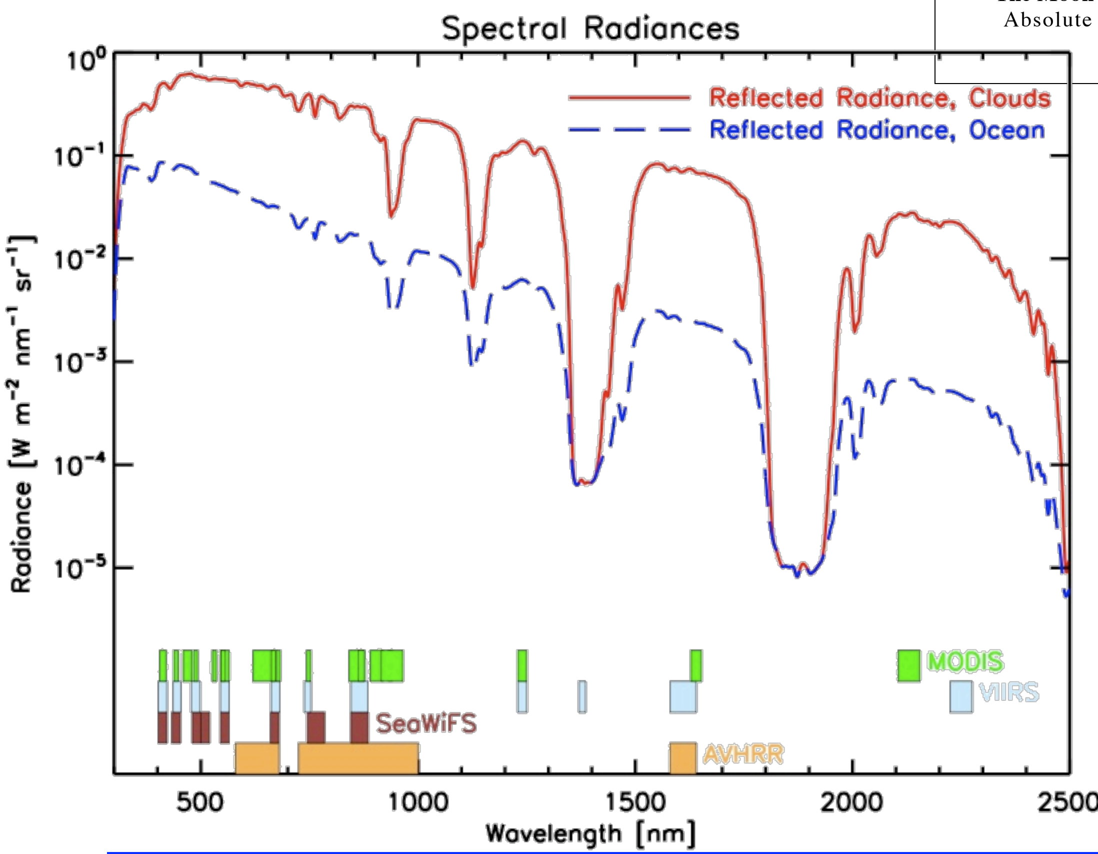


Want Improved Radiometric Accuracies in Visible/NIR

- Current instruments have >2% radiometric accuracy

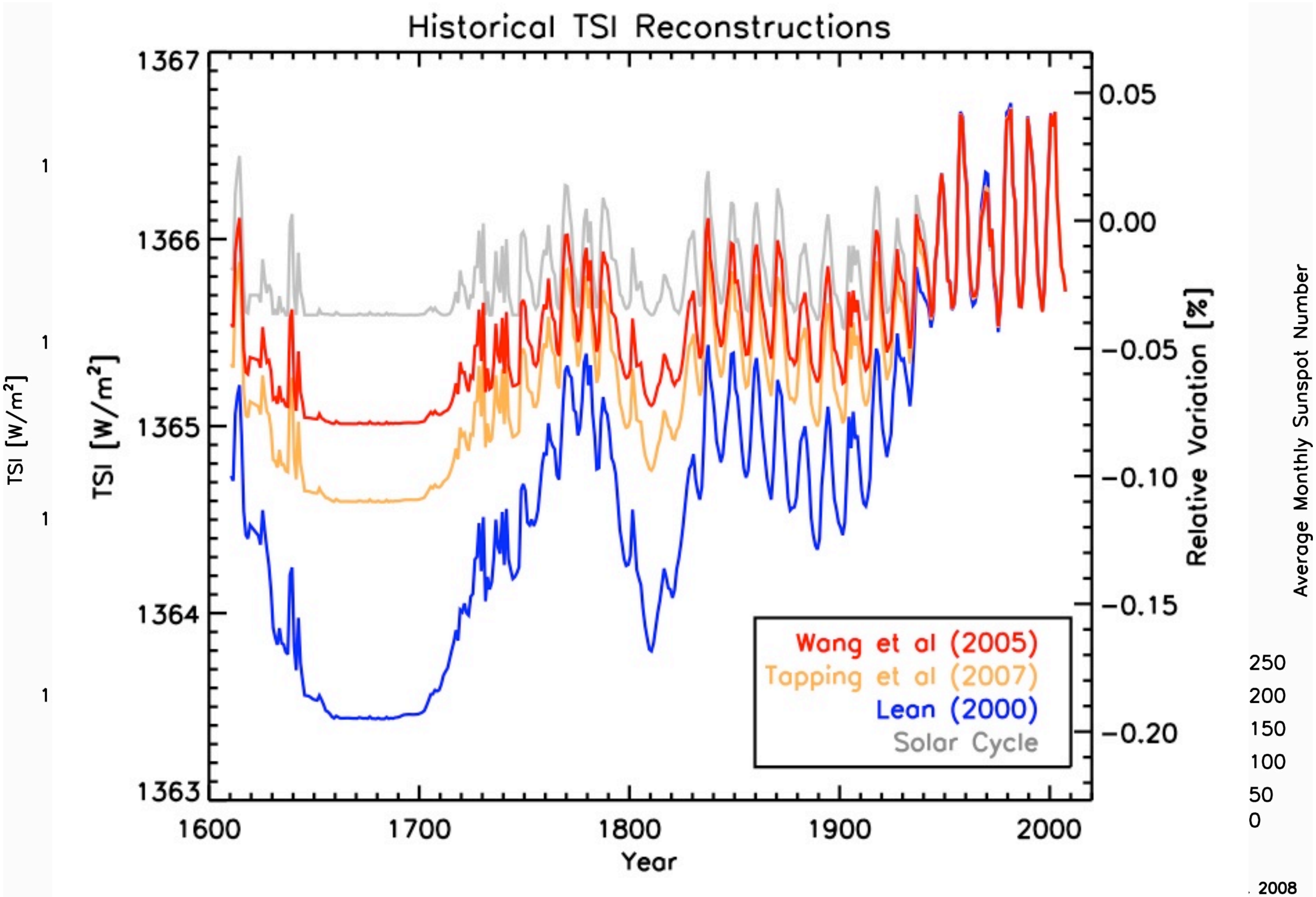
Table 1: Uncertainty Summary for Vicarious Calibration Methods

Methods/Type of Calibration	Uncertainties	Constraints
Artificial Test Sites (Absolute)	• Actual: 3.5% reflectance-based, 2.8% radiance-based • Expected: 2.8% and 1.8%	• Requires ground instrumentation • Requires good atmospheric conditions • Requires specific sensor programming
Stable Deserts Multi-temporal and Multi-sensor	• Actual: 3% • Expected: 1% with BRDF (bandpass dependent)	• Requires specific sensor programming • Requires non-cloudy images
The Moon Multi-temporal	• Expected: 2%	• Dynamic range is limited at high end • Req. specific programming & viewing
The Moon Absolute	• Actual: 5-10% • Expected: 2%	• Dynamic range is limited at high end • Req. specific programming & viewing • Requires low uncertainty calibration and radiometric verification of the moon

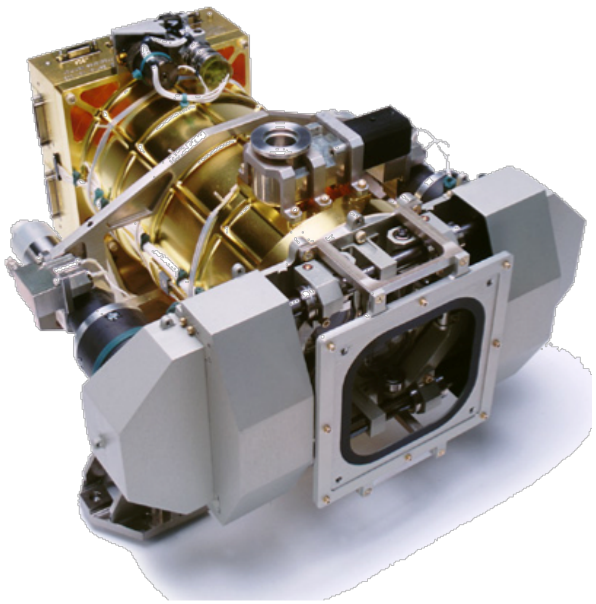


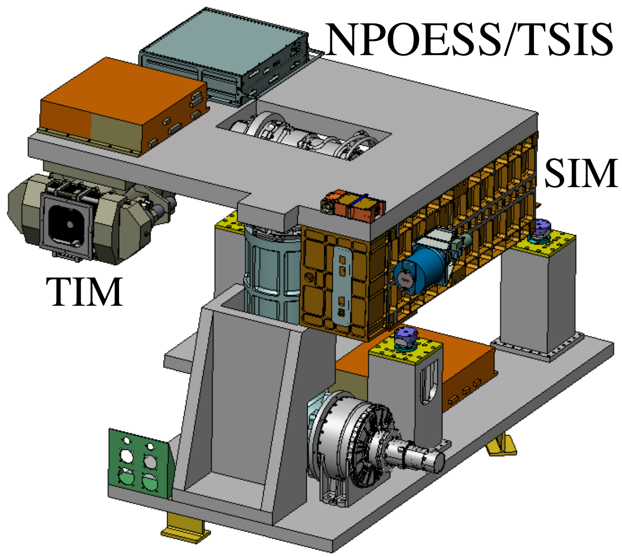
- Accuracy and stability rely on ground calibrations, on-board lamps, cross-calibrations, solar diffusers, or lunar observations

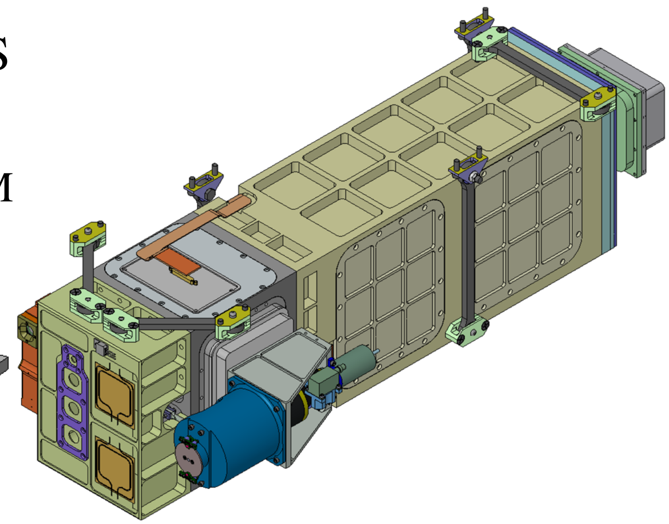
Best-Known Vis/NIR Radiometric Source On-Orbit Is Sun



Active Cavity Radiometers Measure Solar Irradiance







Total Irradiance Monitor (TIM)

- Accuracy 100 ppm (1 σ) → *0.15 K of 5800 K Sun*
- Stability 10 ppm/yr (1 σ)
- Precision 4 ppm (1 σ)

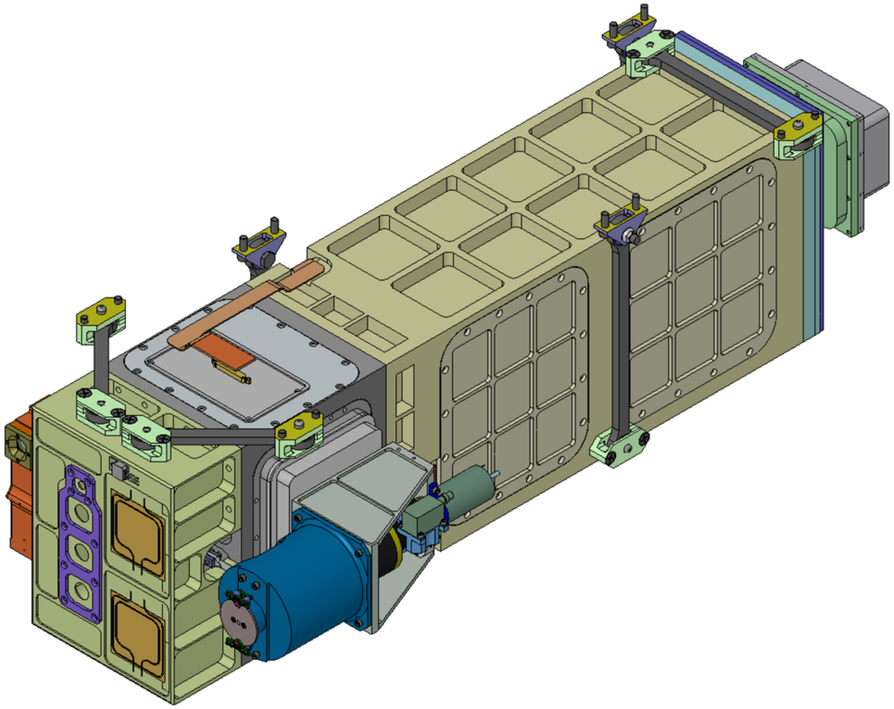
Active cavities tied to electrical references

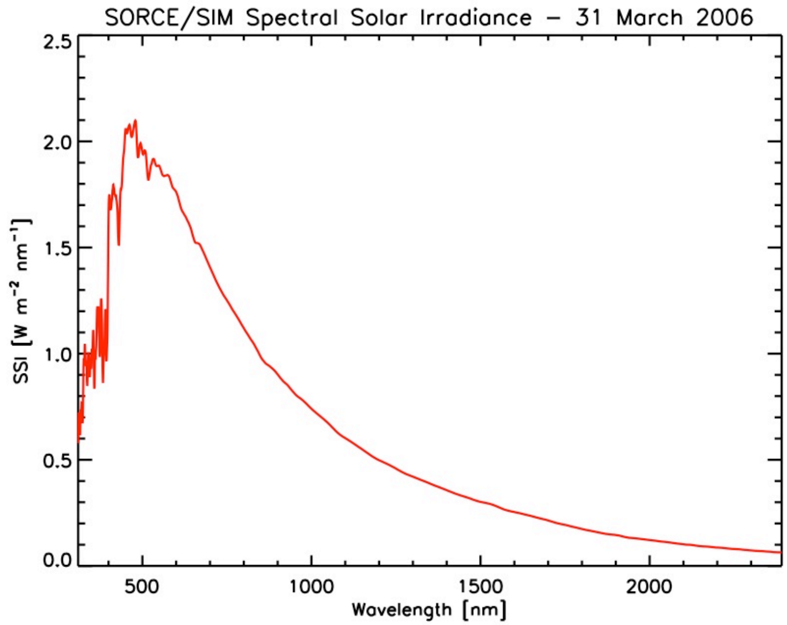
Spectral Irradiance Monitor (SIM)

Measurement Range	0-10 W m^2 nm^{-1}
Accuracy	0.2 %
Long Term Stability	
λ < 600 nm	0.02 %/yr
λ > 600 nm	0.01 %/yr
Precision	0.01 %
Spectral Resolution	
λ< 280 nm	1 nm
280 nm < λ < 400 nm	5 nm
λ > 400 nm	35 nm

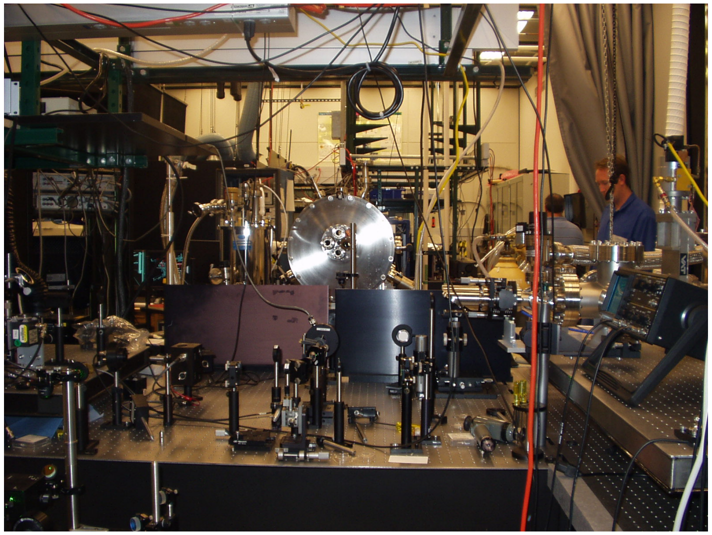
see TSIS poster

Future TSIS/SIM Accuracy 0.1-0.2% With SIRCUS Calibration



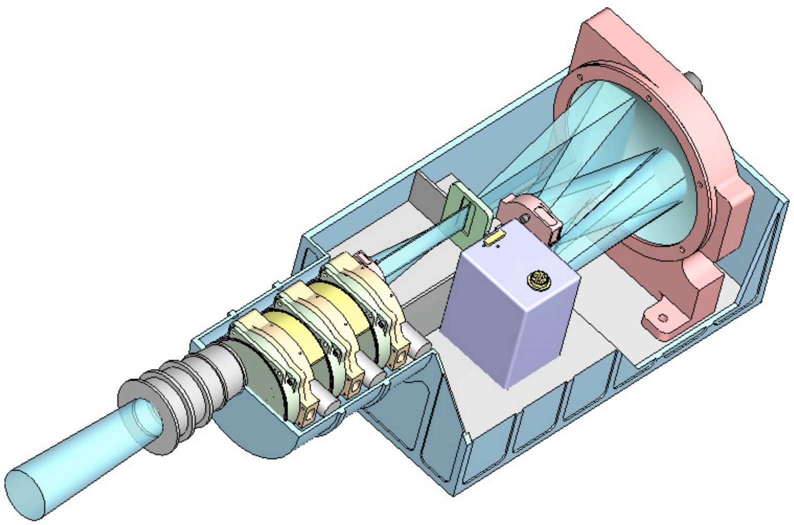


Spectral Irradiance Monitor (SIM) is currently operating on SORCE and intended as part of NPOESS/TSIS.



NIST's Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) enables <0.1% spectral radiometric calibrations.

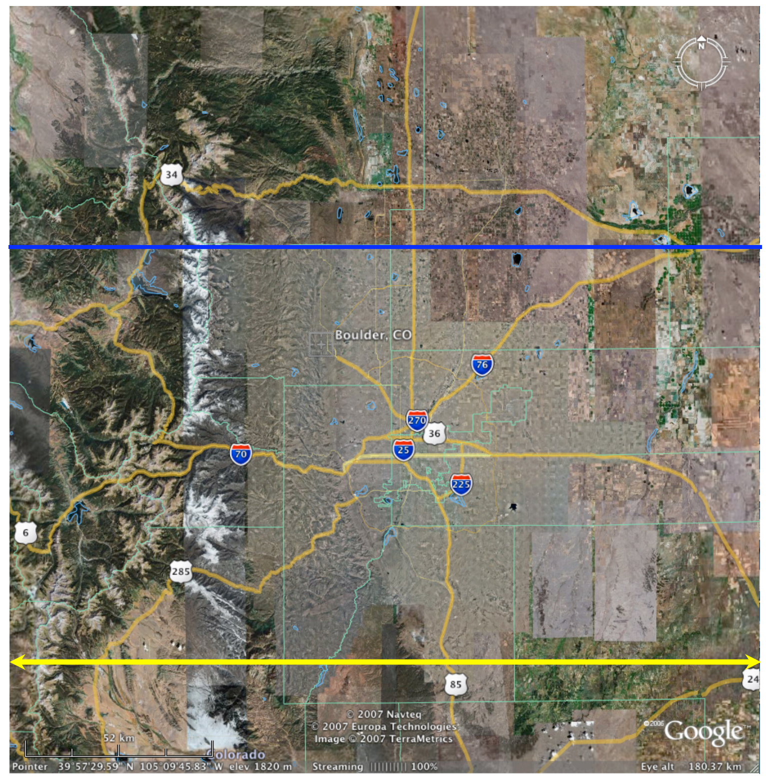
Short-Wave Requirements to Which IIP Is Designed



Hyperspectral Imager Requirements

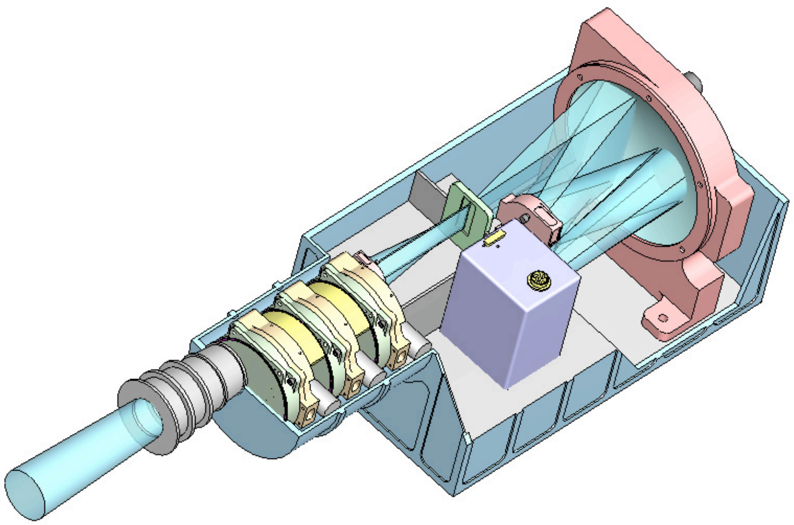
Parameter	Value	Units
Spatial Resolution	0.5	km
Spatial Range (cross-track)	200	km
Wavelength (min)	300	nm
Wavelength (max)	2400	nm
Spectral Resolution	10	nm
Relative Std Uncertainty	0.2	%

0.5 km (2.5 arcmin) IFOV



15° (180 km) (~370 pixels) Earth cross-track

Cross-Calibration Concept



Hyperspectral Imager Requirements

Parameter	Value	Units
Spatial Resolution	0.5	km
Spatial Range (cross-track)	200	km
Wavelength (min)	300	nm
Wavelength (max)	2400	nm
Spectral Resolution	10	nm
Relative Std Uncertainty	0.2	%

Cross-calibration from TSIS gives intended accuracy of 0.2%.

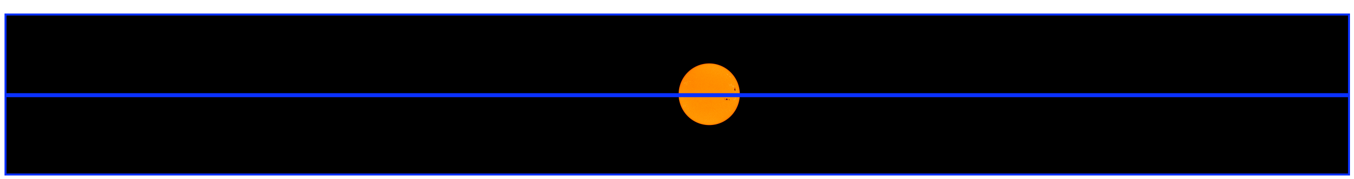
Ratio of reflected (outgoing) to incoming solar radiation measured to <0.2%.

Precisely attenuate sunlight for cross-calibrations with the Total Solar Irradiance Sensor (TSIS)

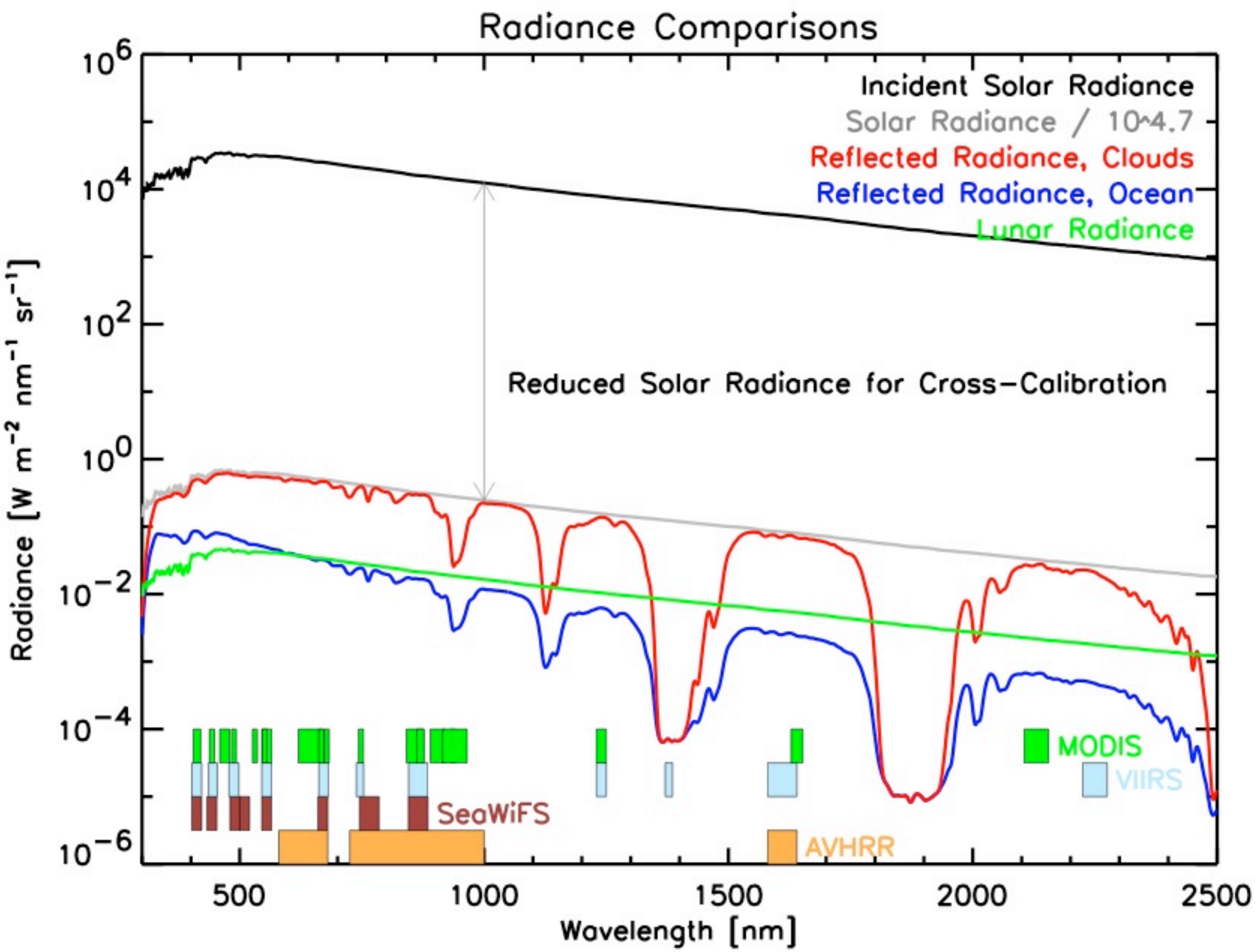
Two spatial/spectral imagers cover 300-1000 and 1000-2400 nm.

Small (~2-cm) telescope optics image the Earth onto spectrographs.

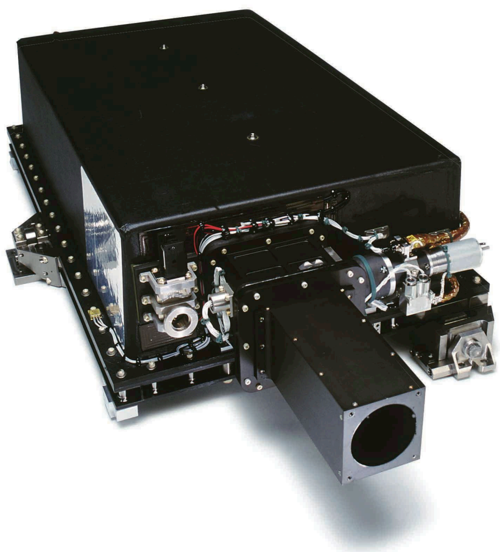
Radiance attenuation methods reduce intensity an accurately known amount, allowing cross-calibrations with Sun.

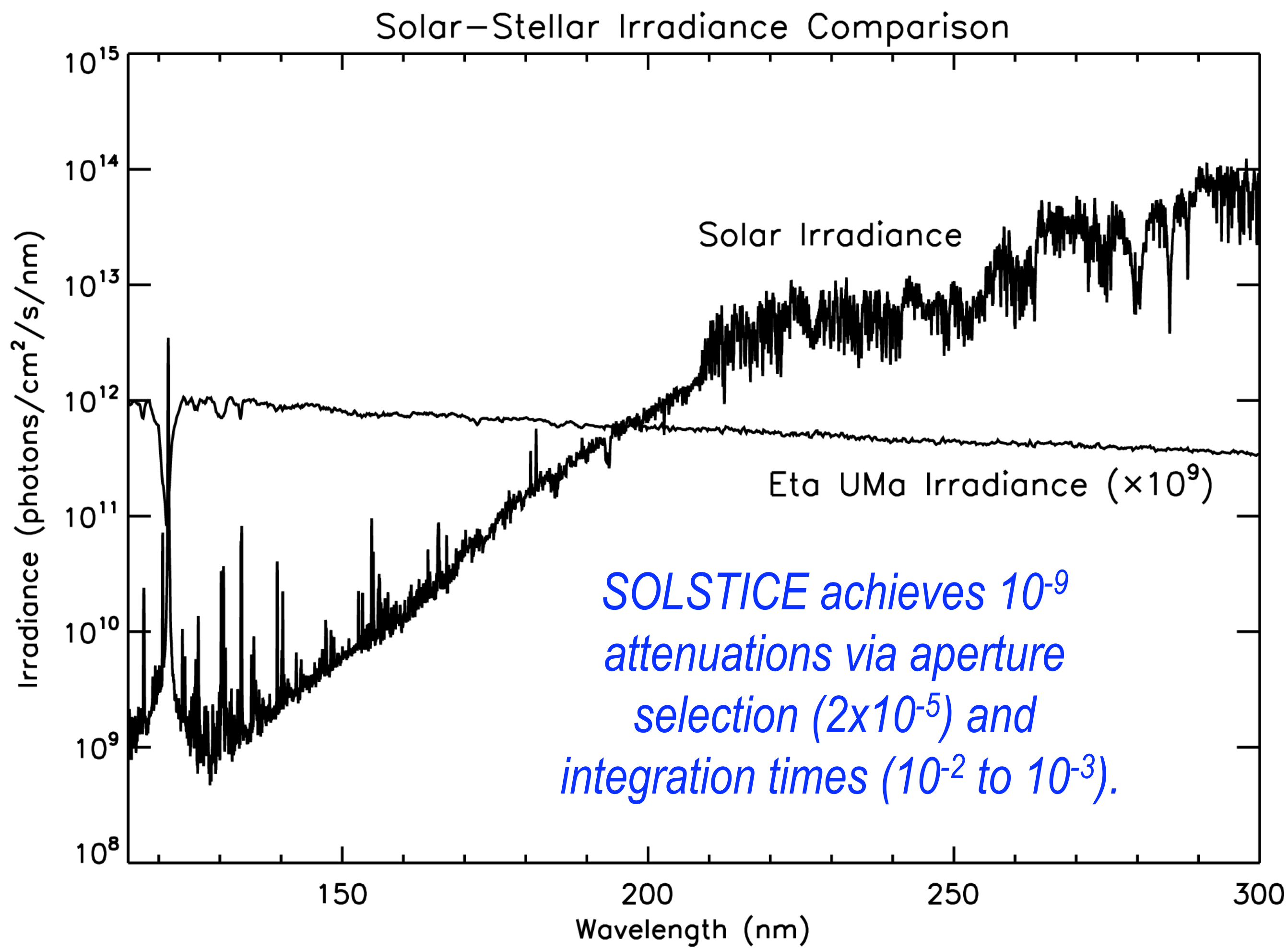


Need ~10^{-5} Attenuation



SOLSTICE Achieves 10^{-9} Attenuation

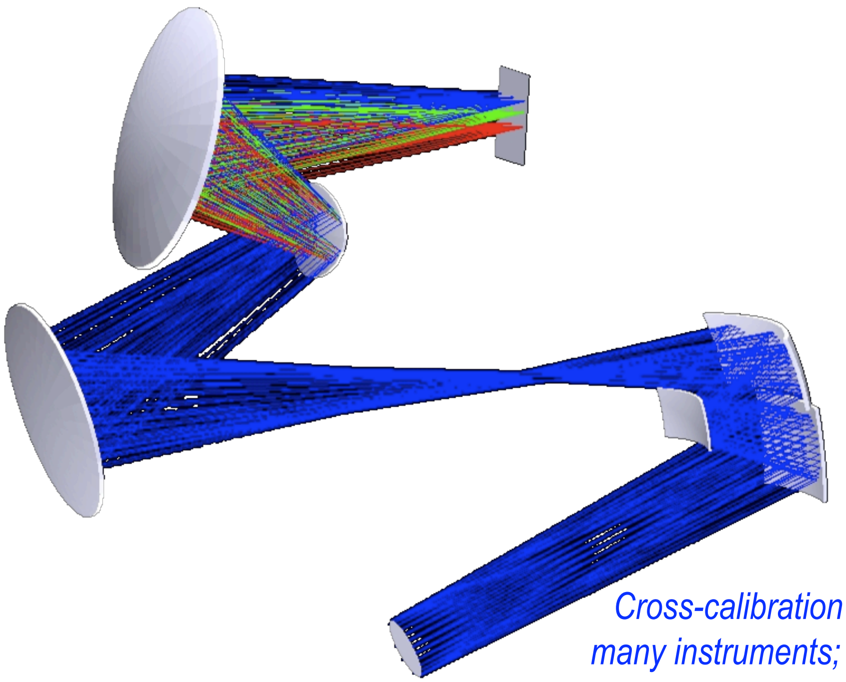


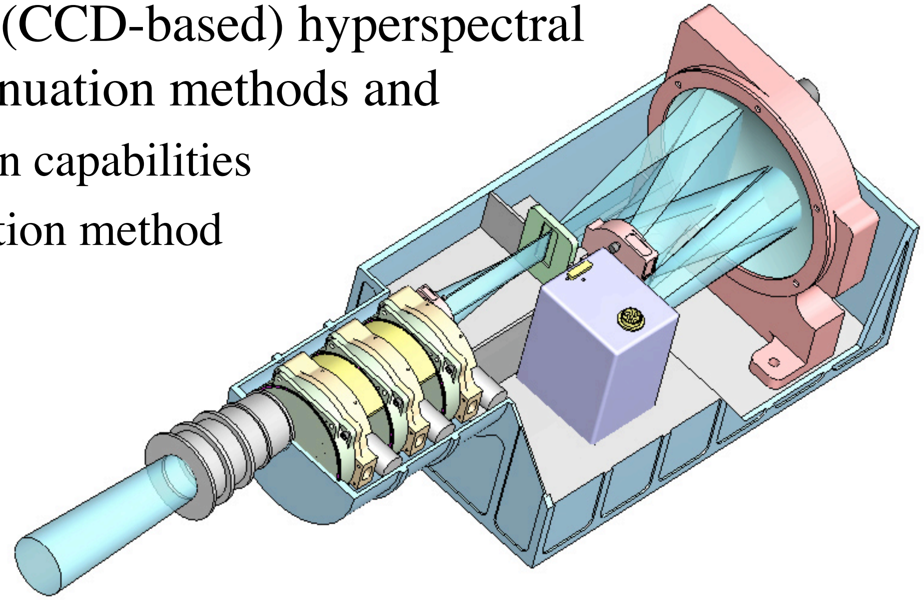


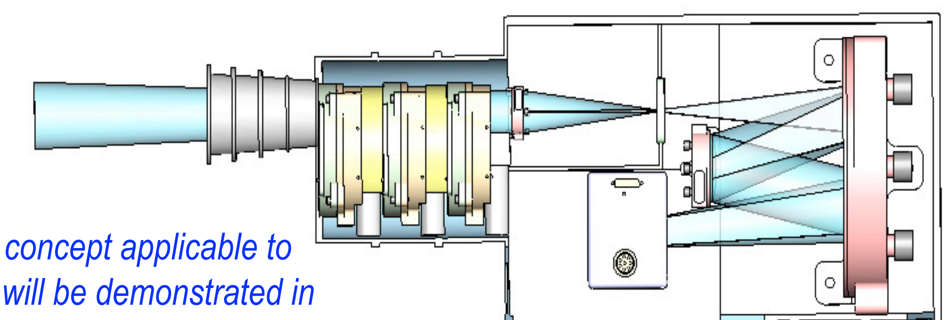
The SOLSTICE instruments flown on UARS and SORCE track stability on-orbit by monitoring stars, which are 9 orders of magnitude dimmer than the Sun.

IIP Overview

- **Intent** is to demonstrate cross-calibration capability from spectral solar irradiance to desired accuracies
- **Method** is to prototype a visible (CCD-based) hyperspectral spectrometer with integrated attenuation methods and
  - Demonstrate accurate attenuation capabilities
  - Show a solar irradiance observation method







Cross-calibration concept applicable to many instruments; will be demonstrated in IIP using a hyperspectral imager.

What About Polarization?

- Polarizers needed on-orbit for calibrations involving moon and instrument characterization
  - Solar radiance is unpolarized to ~10^{-4}, but reflected lunar radiances and instrument are not
- Polarimetry at levels needed for aerosols are much more demanding
  - Requires high polarization purity and co-temporal acquisition of orthogonal polarization states
    - Limited field of view
    - Discrete spectral bands

Trade of spectral continuity, spatial coverage, and radiometric accuracy for highly accurate polarimetric measurements has not been done.

But it should be…

TRLs

- TRL 3
  - Optical design with integrated and accurate solar attenuation methods
- TRL 4
  - Laboratory demonstration of completed hyperspectral imager and solar attenuation mechanisms
- TRL 5
  - Quantified solar attenuation accuracies and solar irradiance measurement method
- TRL 6
  - Demonstration at appropriate radiance levels via ground- or air-based solar observations and Earth scenes

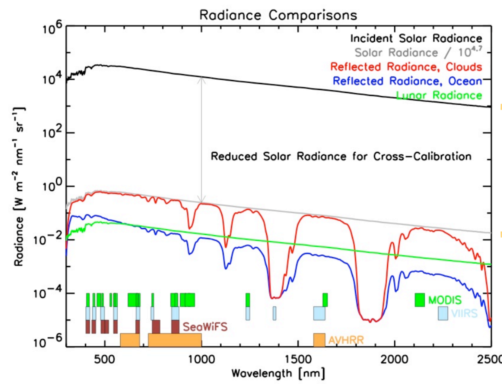
A Hyperspectral Imager to Meet CLARREO Goals of High Absolute Accuracy and On-Orbit SI Traceability

PI: Greg Kopp, LASP

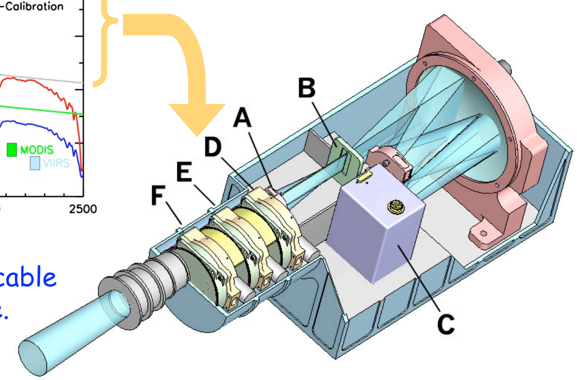
Objective

Improve radiometric accuracy of visible & NIR hyperspectral imaging needed for Earth climate studies via cross-calibrations from spectral solar irradiances.

Enable on-orbit end-to-end spatial/spectral imager radiometric calibrations and degradation tracking with 0.2% SI-traceable accuracy.



Hyperspectral imager components accurately attenuate solar radiances (black) to Earth-viewing radiance levels (red, blue).



Cross-calibration method applicable to 300-2500 nm spectral range.

Approach

Investigate attenuation methods and accuracies allowing a hyperspectral imager to view the Sun and transfer spectral solar radiance measurements to Earth-viewing observations.

Validate solar cross-calibration approach provides desired SI-traceable accuracies using a prototype 300-1050 nm hyperspectral imager with precisely known attenuation methods and a detector calibrated by NIST for linearity across 6 orders of magnitude.

CoI: Peter Pilewskie, LASP

Key Milestones

• Optical Design & Detector Selection	03/2009
• NIST Photodiode Calibrations Complete	09/2009
• Detector Array Tested	06/2010
• Operating Spectrometer (TRL 4)	08/2010
• Quantified Attenuation Uncertainties (TRL 5)	04/2011
• Lab Calibrations & Field Studies (TRL 6)	06/2011

TRL_{in} = 3

ESTO Earth Science Technology Office